

# ENCAPSULATION FOR PARTICLE ENTRAPMENT

## CROSS-REFERENCE TO RELATED APPLICATIONS

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The following patents and/or commonly assigned patent applications are hereby incorporated herein by reference:

5	Patent No.	Filing Date	Issue Date	Title
	09/311,009	May 13, 1999		Spring-Ring Micromechanical Device

## FIELD OF THE INVENTION

This invention relates to the manufacture of micromechanical devices, more particularly to packaging of micromechanical devices such as micromirror devices.

## BACKGROUND OF THE INVENTION

Micromechanical devices are small structures typically fabricated on a semiconductor wafer using techniques such as optical lithography, doping, metal sputtering, oxide deposition, and plasma etching similar to those developed for the fabrication of integrated circuits.

Digital micromirror devices (DMDs), sometimes referred to as deformable micromirror devices, are a type of micromechanical device. Other types of micromechanical devices include accelerometers, pressure and flow sensors, gears and motors. While some micromechanical devices, such as pressure sensors, flow sensors, and DMDs have found commercial success, other types have not yet become commercially viable.

One problem common to most micromechanical devices is the problem of particulate contamination. While some micromechanical devices, such as pressure sensors, may not have exposed moving parts, most devices do have exposed components that move relative to each other. These moving parts can become mechanically blocked or electrically shorted by very small particles of debris. Although steps are taken during manufacture of the devices to clean

debris from the devices, the fragile nature of some micromechanical devices and other factors conspire to prevent total elimination of the debris. Thus, debris inside micromechanical packages continues to be a significant cause of mechanical and electrical failures. What is needed is a way to prevent these failures caused by debris inside the micromechanical device

5 package.

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## SUMMARY OF THE INVENTION

Objects and advantages will be obvious, and will in part appear hereinafter and will be accomplished by the present invention which provides a method and system for encapsulating debris-generating regions of the micromechanical devices. One embodiment of the claimed invention provides a method of protecting debris-intolerant micromechanical devices. The method comprises attaching a device to a substrate, encapsulating at least one debris-generating region with a blocking material, while avoiding contact between the blocking material and any debris-intolerant regions.

According to another embodiment of the claimed invention, a packaged micromechanical device is provided. The packaged micromechanical device comprises a package substrate, a micromechanical device supported by the package substrate and having at least one debris-generating region, blocking material attached to the device and covering at least one debris-generating region, and a package lid supported by the package substrate and enclosing the micromechanical device and the blocking material.

Advantages of the claimed method and system include the permanent blocking of debris generated by the debris-generating portions of the device. The debris-generating portions of the device include debris-creating regions such as the device sidewalls, and debris-harboring regions such as cavities under the device and other portions of the device, including the sidewall, that can trap debris and later release it. The blocking material not only provides permanent entrapment of debris, but entrapment of the debris is often cheaper than methods of eliminating the existing debris, such as cleansing or scrubbing the devices. While scrubbing the device can remove loose particles that have not yet broken off the device, scrubbing cannot prevent the device from creating particles in the future. An additional benefit of the blocking material is due



## BRIEF DESCRIPTION OF THE DRAWINGS

For a more complete understanding of the present invention, and the advantages thereof, reference is now made to the following descriptions taken in conjunction with the accompanying drawings, in which:

5       FIGURE 1 is a perspective view of a micromechanical device, such as a digital micromirror device (DMD™), mounted to a package substrate.

FIGURE 2 is a cross-section side view of the device and package substrate of Figure 1 showing bond wires connecting the bond pads on the device to those on the package substrate.

FIGURE 3 is a cross-section side view of the device of Figure 2 showing a quantity of blocking material deposited around and under the device.

FIGURE 4 is a cross-section view of the device of Figure 3 showing the blocking material covering not only the sidewalls and debris-harboring regions of the device, but the bond wires as well.

FIGURE 5 is a schematic side view showing a typical application method using a syringe and two moveable X-Y stages.

FIGURE 6 is a cross-section side view of a device completely enclosed by blocking material.

FIGURE 7 is a cross-section side view of the device of Figure 6 having a portion of the blocking material removed to expose debris-sensitive regions of the device.

20       FIGURE 8 is a cross-section side view of the device of Figure 4 sealed in a package cavity.

## DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

A new system and method has been developed to eliminate many of the debris-caused failures of micromechanical devices. These failures are eliminated by encapsulating the debris such that it cannot migrate to debris sensitive portions of the micromechanical device. The debris is encapsulated in place over portions of the device that are tolerant of the encapsulating material. The encapsulating material avoids regions of the micromechanical device, such as exposed moving components, that would be harmed by contact with the encapsulating material. In addition to encapsulating existing debris, the encapsulating material is also deposited over regions of the device that have been determined to generate significant quantities of debris. These regions typically include the sidewalls of the silicon substrates on which many micromechanical devices are formed.

Figure 1 is a perspective view of a micromechanical device 100 such as a digital micromirror device (DMD™) mounted to a package substrate 102. Figure 1, like the rest of the figures shown, is not drawn to scale but is drawing to illustrate particular features relevant to the invention disclosed herein. The device 100 in Figure 1 is a portion of a silicon wafer on which a micromechanical device has been formed. The device has a debris intolerant area, which in the case of a DMD includes the array of mirrors. The perimeter of the device, and a region of the package surrounding the device, includes many bond pads 106 that allow electrical connection between the device and the package.

Figure 2 is a cross-section side view of the device 100 and package substrate 102 of Figure 1 showing bond wires 108 connecting the bond pads 106 on the device to those on the package substrate 102. Two regions of the device shown in Figure 2 tend to be debris-generators. First, the side of the device, or sidewall 110, tends to create debris throughout the

life of the device. The sidewall 110 is the portion of the device that is fractured when the device is separated from a silicon wafer. The separation process, whether performed by breaking the wafer or sawing the wafer, creates many fissures in the silicon crystal wafer. As the device undergoes thermal cycles and vibration, these fissures can grow and release silicon debris. Thus, even if all of the debris is washed from the device after wafer separation, the device itself can generate additional debris even after the device is hermetically sealed in a package.

The second class of debris-generating regions trap, and later release, debris. For example, debris can be trapped under the device in a gap 112 formed by voids in the adhesive 114 used to attach the device 100 to the package substrate 102, or in other regions that are difficult to rinse debris out of.

According to one aspect of the present invention, a blocking material is deposited on either the debris generating, or debris harboring regions, or both, to prevent debris from being released or generated by the device and migrating to the debris-intolerant portions of the device. Typically, the blocking material is an adhesive that is deposited around the perimeter of the device after the device is attached to the package substrate.

Figure 3 is a cross-section side view of the device of Figure 2 showing a quantity of blocking material 116 that has been deposited around and under the device 100. As shown in Figure 3, the blocking material 116 surrounds the device 100, encapsulating the debris-creating sidewall regions and either filling the debris-harboring regions or blocking debris from exiting the debris-harboring regions 112. The blocking material of Figure 3 avoids the debris-sensitive regions 118 of the device 100. In Figure 3, the device 100 is a digital micromirror device and the debris-sensitive region is the array of micromirrors on the surface of the device 100.

Figure 4 is a cross-section view of the device 100 of Figure 3 showing the blocking material 116 covering not only the sidewalls and debris-harboring regions of the device 100, but the bond wires as well. Encapsulating the bond wires is sometimes necessary in order to cover the sidewalls 110 of a device 100 after the device 100 has been bonded to the package substrate 102 and electrically connected using bond wires 108. Encapsulating the bond wires 108 not only is necessary, it may improve operation of the device in a high-vibration environment.

The ideal blocking material should be easy to apply to the device 100 with sufficient control to ensure coverage of the debris-creating and harboring regions without allowing the blocking material 116 to reach the debris-sensitive regions. Additionally, the blocking material 116 should adhere to the device and other surfaces sufficiently to prevent the material from coming free of the device surface. One family of compounds that is ideally suited for use as a blocking material is the family of photo-curable adhesives. Two particularly well-suited adhesives are NOA88 and NEA123, both UV-curable optically-clear adhesives produced by Norland Corporation. While NOA88 and NEA123 harden when they are cured, compounds that remain sticky could provide a gettering function inside the package as well as a blocking function.

When used with digital micromirror devices, which must be undercut to remove the photoresist on which the micromirrors are formed, the devices 100 are typically undercut prior to bonding the device 100 to a package substrate 102. If the process flow uses the recently-developed method of attaching the device 100 to the package substrate 102 prior to undercutting the micromirrors, the blocking material may be applied prior to, or after, the mirrors are undercut. Preferably, the blocking material is applied prior to undercutting the micromirrors. In this manner, the debris is prevented before the micromirrors become sensitive to the debris. If



the blocking material is applied before the undercutting process—a plasma etch process—the blocking material must be able to withstand the undercutting process without significant degradation.

The blocking material is applied in a variety of ways. The typical application method uses a syringe 120, shown in Figure 5, to expel blocking material while the syringe 120 and device 100 are moved relative to each other, typically by use of an X-Y stage 122. The syringe 120 can be either a positive displacement or a pneumatic syringe. The amount of blocking material deposited is controlled by the rate of movement of the syringe 120 plunger and the rate of relative motion generated by the X-Y stage. Examples of suitable syringes 120 include positive displacement syringes, in which a motor controls movement of the plunger, and pneumatic syringes, in which the plunger is controlled by air pressure. Many other application methods, such as spraying or dipping, can be used without departing from the teachings of this disclosure.

A second method of applying the blocking material is shown in Figures 6 and 7. In Figure 6, the blocking material completely encloses or pots the device. A portion of the blocking material 116 is then removed, as shown in Figure 7, to expose the debris-sensitive regions 118 of the device 100. Selective removal of the blocking material 116 is accomplished by photolithographic processes using masks, by selectively curing part of the blocking material and removing the uncured material, or through the use of other means. While the encapsulate and remove process requires additional steps and is therefore expected to be more cumbersome and expensive, it can provide very precise location of the blocking material if necessary. For example, the blocking material can be removed to form an aperture over an optically active region of the device.

Figure 8 is a cross-section side view of a packaged micromechanical device 100 showing use of blocking material 116 to prevent the generation of debris that could interfere with the operation of the micromechanical device 199. In Figure 8, the debris-generating regions of the device 100, including the debris-creating sidewalls and any debris-harboring cavities, as well as the electrical connections 108 linking the device 100 to the package substrate 102 are encapsulated by the blocking material 116. The blocking material 116 avoids contact with any debris-intolerant regions 118 of the device 100. A package lid 122, which is glass in the case of many DMD packages, seals the device 100 in a package cavity 120.

The blocking material 116 not only provides permanent entrapment of debris, including debris generated after the device is packaged, but entrapment of the debris is often cheaper than methods of eliminating the existing debris, such as scrubbing the devices. While scrubbing the device will remove loose particles that have not yet broken off the device, scrubbing cannot prevent the device from generating particles in the future. An additional benefit of the blocking material 116 is the reduction in package cavity volume when the blocking material 116 is used. Since the cavity volume is reduced, the environmental effects on the packaged device are also reduced since there are fewer captured gasses to react with the device.

Thus, although there has been disclosed to this point a particular embodiment of sidewall encapsulation and method therefore, it is not intended that such specific references be considered as limitations upon the scope of this invention except insofar as set forth in the following claims. Furthermore, having described the invention in connection with certain specific embodiments thereof, it is to be understood that further modifications may now suggest themselves to those skilled in the art, it is intended to cover all such modifications as fall within the scope of the appended claims.